An upper ocean model of the planktonic ecosystem of the Eastern Subarctic Pacific

The vertically resolved, process-based, numerical model presented in this work serves to critique the standard picture of planktonic dynamics in the eastern subarctic Pacific. The modelled phytoplankton community consists of a small ($< 10\ \mu$m) size fraction of low-iron-adapted phytoplankton (P_n) grazed by microzooplankton and the iron-stressed micro-diatoms grazed by ontogenetic mesozooplankton migrants, primarily large calanoid copepods of *Neocalanus* spp. Two approaches are used to include the effects of iron limitation: in the first, an iron dependence is implicit in diatom growth rate parameters and, in the second, diatom growth is an explicit function of bioavailable soluble iron concentration whose dynamic evolution is defined by a partial differential equation. A copepod life cycle model (LCM) is presented which couples dynamically to the ecosystem model, thus, incorporating population migration patterns and weight and maturity distributions in the omnivorous "predation closures" of the micro-plankton equations. In addition, model observations of population weight and weight at diapause provide time-dependent diagnostic information about the health and fecundity of the pelagic copepodid population. The LCM and ecosystem model, coupled with the KPP ocean boundary layer model of Large et al. (1994)[1], reproduces quasi-equilibrium annual cycles of observables in the northeastern Pacific planktonic ecosystem while maintaining equation parameterizations consistent with physical and biological processes.

1   Ecosystem Model

The planktonic ecosystem model consists of eight model properties: z-dependent nitrogen density pools for which coupled partial differential equations define temporal evolution. In the notation of this work, z is positive upward and t is time. Figure 1 is the model schematic. Phytoplankton are divided into two classes: the $< 10\,\mu$m size fraction P_n of pico- and nanoplankton, which dominates phytoplankton biomass and is assumed to grow at rates consistent with natural light and ambient nutrient levels; and the micro-phytoplankton P_d which is characterized by the centric diatom and assumed to have depressed nitrogen uptake rates due to low in-situ soluble iron concentrations. Size has further implications: P_d are sinking particulates while P_n form a suspended pool, as well, trophic interactions follow a broad size classification. The microzooplankton Z_f are assumed strict heterotrophs and graze only the smallest phytoplankton class (P_n), while omnivorous mesozooplankton, modelled after the region's dominant migratory copepods, *Neocalanus plumchrus*, effectively graze the "micro" size fractions: P_d, Z_f, and sinking detritus D_b. The remaining nitrogen pools consist of suspended detritus D_a and dissolved nitrogen: nitrate plus nitrite N_o and the remineralized pool, ammonium plus urea N_h.
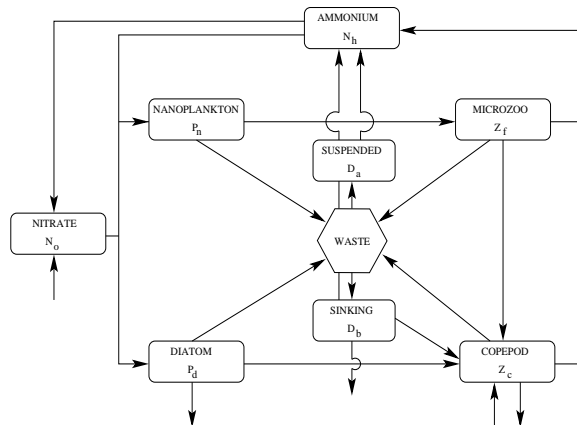

Figure 1: Schematic of model structure: arrows between boxes indicate the direction of nitrogen flow between model properties in the upper ocean. Open-ended '↓' and '↑' represent exchanges with the mesopelagic below the model domain of 200 m. Detritus is composed of suspended (D_a) and sinking (D_b) fractions.

2 The Quasi-Equilibrium Solution

I use the following procedure to determine base state model (BASE) parameters. First, whenever possible, reaction functions and parameters are constrained by experimental and theoretical studies, independently of model runs. Note, although the source and sink functions are certainly not unique representations of the respective processes, they are consistent with experimental results and assumptions concerning the plankton communities. Second, model parameters are tuned until modelled output compares favorably with OSP planktonic observables: seasonal mixed layer ($m.l. \equiv$ the shallowest depth for which temperature $T(z) = T(0) - 0.1$ in ^{o}C) averages of size fractionated phytoplankton, microzooplankton, nitrate, ammonium, total particulate organic nitrogen, density specific phytoplankton growth rates and P_n ingestion mortality, 150 m averages of mesozooplankton, euphotic zone ($e.z. \equiv 1\% I_{par}$ depth), averaged f-ratio ($\rho N_o/[\rho N_o + \rho N_h]$), total primary production $PP = PP|_n + PP|_d$ in the $e.z.$, and PON 200 m flux. Parameterization of the physical model is consistent with Large et al. (1994) as are parameter values for horizontal advection and upwelling.

Figure 2 contains two week averages from modelled solutions of year two using BASE(2) parameters.
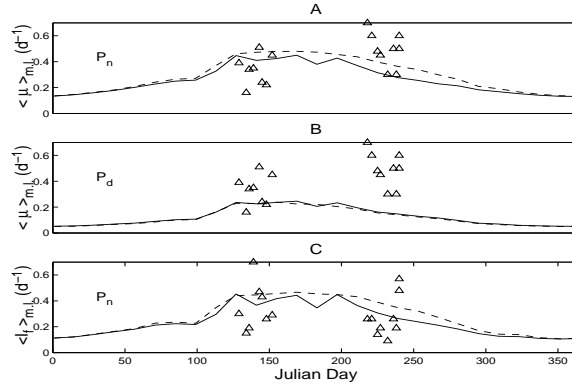

Figure 2: BASE ($-$) and BASE2 ($--$) solutions of density specific phytoplankton growth rates for (A) P_n and (B) P_d averaged over the mixed layer ($m.l.$). Results compare favorably with OSP estimates ($\triangle$, [2]).

Mixed layer ($m.l.$) averaged specific growth rates ($\mu|_n$ and $\mu|_d$) shown in figure 2 compare favorably with Miller et al. (1991)'s estimates of community growth rates at OSP. In the quasi-equilibrium seasonal cycle, P_d growth rates are consistently less than P_n, and values for both plankton pools bound the lower estimates at OSP. Not surprisingly, PP modelled values also bracket the conservative estimates. In the OSP simulations of Pondaven et al. ([3],1999), comparable P_d specific growth rates ($\sim 0.3\,d^{-1}$) are necessary to prevent a spring diatom bloom. Specific growth rates for P_n and P_d with BASE parameters under optimal light and nutrient conditions, however, have the potential for increases of ~ 3–$4\times$ the above values: ~ 1.2 and $\sim 0.8\,d^{-1}$, respectively. It is worth noting that P_d grow at depressed rates under all ambient light and macro-nutrient conditions. Thus, changes in mixing and irradiance considered in model experiments are not sufficient to relieve "iron stress" in P_d.

References

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